SYSTEMATIC BREEDING DECISIONS MADE WITHIN A VERTICALLY INTEGRATED BEEF SUPPLY CHAIN

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ABSTRACT

This paper investigates how to use a vertically integrated supply-chain model to aid in the selection of beef sires when making breeding decisions. A systematic approach was taken to model and determine the benefits and associated sire rankings arising from the simulated mating of parent stock to create progeny for use within a vertically integrated supply chain. Supply chain-wide gross margins serve as the benefit measure. Supply chain revenues are in the form of quality indexed retail product revenue. Quality indexing (i.e. discounting) factors included intramuscular fat and longissimus muscle (i.e. ribeye) area. A fixed and an optimum endpoint (i.e. harvest) selection method are compared. Varying progeny gross margins and sire rankings were produced. The various levels of gross margin were significantly different from zero, and provide a clear means by which to incorporate economic variables into selection of beef sires. No current method of selecting parental stock returns similar results.

Key words: value-chain management, beef-cattle breeding

INTRODUCTION

In an animal based marketing channel, upstream and downstream participants have competing interests brought about by the simple buyer-seller relationship. However, in the context of the entire supply chain, the main objective of all supply chain members is to satisfy one economic agent, namely the consumer. In a non-integrated supply chain, information regarding consumer preferences for retail product may not be fully disseminated back to upstream agents via information sharing or pricing mechanisms. While the causes of such poor information flow are varied, the consequences are not. Poor information flow within a marketing channel will result in sub-optimal decision-making and potential unrealized economic benefits. In response to this, various sectors in the agri-food industry have begun to use integrated supply chains. In these supply chains, decisions are made with the economic well-being of all supply chain participants borne in mind. Such a collective approach requires improved information flow, but typically results in greater economic benefits.

In attempting to satisfy the consumer, the chain has incentive to cooperate. Recognize, however, that the degree to which the value-chain participants cooperate varies with the degree of integration. This study examines supply chain benefits in a very specific and extreme example of cooperation, namely full vertical integration. Through full vertical integration, thorough accounting of costs and revenues associated with the decisions made within the chain is possible, presumably to the benefit of supply chain members. The use of the vertically integrated framework in this context is supported by the work of Coase (1937) and Williamson (1979).[5]

Supply chain integration in animal agriculture has been occurring for some time now. As the animal agriculture industry becomes more integrated, processors and producers will begin to share more information. Understanding what is possible from upstream and downstream

[5] See also Grossman and Hart (1986).

members' co-operation has become more important. With increased co-operation and information sharing comes increased understanding of product attributes favored by consumers and producers within the animal agri-food supply chain. Increased co-operation and information sharing also increases the scope for higher margins throughout the value-chain.

To date, integration of the animal agri-food supply chains has favored the swine and poultry industries. The little integration that has occurred in the beef sector has led to some questioning of the structure of its supply chain. The structural organization of beef supply chains may be creating asymmetry in trait pricing, resulting in chain wide, sub-optimal breeding decisions. The creation of an integrated production model to calculate chain-wide benefits of individual animals is required. Once chain-wide benefits for an individual animal can be determined, a ranking of parents used to create that animal can be created and compared. Comparison of progeny rankings will create a starting point from which one can determine how decision makers within an integrated supply chain might make breeding decisions resulting in a Pareto improvement.

The purpose of this paper is to explore how the inclusion of downstream supply chain information regarding beef (i.e. output) quality influences upstream breeding (i.e. capital investment) decisions. This is accomplished by developing an integrated beef supply chain model to aid in calculating chain-wide benefits arising from selection of beef sires. The value-added of this approach is the joining of an economic model (for the supply chain) with a biological model (reflecting progeny growth) to help measure the economic value of a particular sire/dam mating. Chain benefits will then be used to rank each sire considered. For comparative purposes, the sire ranks based on chain wide benefits are then compared to sire ranks based on ranking models developed in the animal science literature. The point is to illustrate how economic measures can be used to guide sire selection decisions, and how ranking of sires from such application compare to other ranking methods.

Previous work illustrates the value of using a chain wide approach in analyzing livestock and meat sectors. Goldsmith et al (2003) investigated the social welfare consequences related to optimal hog slaughter weight using a model reflecting both producer and processor welfare. Moreover, their model also included a biological component that allows for a differential impact of various production and husbandry decisions on animal growth. Poray et al (2003) also took a chain approach when comparing alternative marketing systems and strategies in the U.S. hog/pork sector. Like the model that follows, they also included physical and financial flows. Nevertheless, the literature is somewhat silent with respect to beef supply-chain models, a void which this paper fills.

CONCEPTUAL FRAMEWORK

An integrated supply chain accomplishes the same task as a non-integrated supply chain, namely marshalling inputs through a production process which ultimately provide consumers with a final product. The integrated supply chain, however, replaces market based linkages between economic agents with direct output and information flows, and involves chain-wide decision-making and marketing decisions. Moreover, rather than procuring inputs and selling outputs via market transactions (or contractual arrangements), procurement and provision of inputs/outputs occurs via internal transfer within the chain (e.g. within a fully integrated firm).

To determine the economic benefits and costs of various decisions made within a supply chain, connections between many different activities and agents are required. Within a generalized animal supply chain these activities include: selection and mating of parent stock; management of progeny to determine growth and product composition; processing of progeny with varying composition to derive end products that are demanded by consumers; and determining the value consumers place on varying composition of the end products.

An important component in selecting genetics is defining the environment under which parents and progeny will exist. In the model developed here, these environments are held fixed and constant and are specific to the modeled supply chain. Within this environment, however, the pairing of parent stock is varied. Consequently, the genetic characteristic of progeny also varies. Progeny are all evaluated in the same production environment for a single purpose; that purpose being for use as retail beef cuts to be consumed. Recognize, however, that if consumer valuation for the end product changes, then so too must the progeny's genetic characteristics. Only through a change in the genetic make up, and expression of this make up via product characteristics, will supply channel members benefit.

Choice of parental stock is also governed by the importance of quality and quantity of progeny growth. The ability to determine the levels of quantity and quality of growth is required if economic agents value both aspects of growth differently. In an animal supply chain, quantity of growth is measured in weight (e.g. the weight of a bovine at 365 days of age), while quality of growth might be measured as weight of lean meat or some other measure (e.g. percentage intramuscular fat within the longissimus muscle). The quantity and quality of growth has an impact on the products derived from each progeny. By the same token, progeny with different traits will yield various levels of usable products and products which might be a financial burden on the processor.

Finally, determining the revenue to be obtained from the sale of useable product derived from progeny, and fully accounting for the costs associated with doing so, will yield benefits for the supply channel from decisions made upstream. Depending on the composition of usable product, there may be a value differential placed on the product by consumers. Adjusting revenue for end product composition requires a quality-indexing factor. For example, if beef cuts are valued differently based on the amount of intramuscular fat (i.e. marbling), the value of those cuts needs to be taken into account. As well, there are some decisions which affect costs, some which affect revenue, and some which affect both costs and revenues. Full accounting of the costs and revenues related to upstream decisions is required when the perspective is that of a vertically integrated framework.

Figure 1 provides a conceptual basis for the supply chain model that follows. The supply chain is composed of four distinct units: a retailing unit, a processing unit, a growing unit and a retailing unit. These units are assumed to be under the control of the supply chain manager, who takes consumer values, as well as external factors, and makes managerial decisions to maximize supply chain benefits within the context of the management environment.[6] (The box with bold outline delineates the extent of the supply chain environment.) It is important to note that consumer value is assumed to be transmitted across the entire chain in the form of information used in decision making and when pairing sires and dams for the breeding decision.

Final demand provides information to the supply chain manager via actual transactions and direct communication. This information is then internalized within the chain to influence the management decisions which have a bearing on the quality and quantity of final product made available. This influence may affect any number of decisions, such as the number of animals to

[6] External factors play a role by shaping consumer's valuation of the chains product via changing tastes and preferences, scope for competing or substitute products, income and other demand related variables (these are held fixed in this study). Factors external to the firm include items such as the price of purchased inputs, the legal environment and governance issues, available technologies and macro-economic factors (all of which are held fixed).

have on feed, the nature of the feed ration, time of feed, nature of the rearing/confinement environment, etc. Moreover, this influence may be realized at many levels of the supply chain.

Of direct consequence here, information goes to assist in making sire and dam selections which results in end product that meets consumer's requirements, both in terms of quality and quantity. Information shapes sire or dam selection via criteria employed by producers or animal breeds. Typically these criteria relate to phenotypic trait(s) of the progeny arising from parent stock selection. However, focusing on a single (or multiple) trait loses sight of the fact that profit matters when making decisions in an economic environment, and that what really matters to producers is the cumulative value of the phenotypic traits of the progeny. The analogy is one of maximizing production versus maximizing profit – under these two decision criteria, different production mixes (i.e. either input or output mixes) will be employed. Moreover, it is often the case that maximizing production results in sub-optimal decisions in an economic context (i.e. less profit).

In this instance, optimal sire/dam selection should be one where the value of the resulting progeny maximizes chain wide benefits. For our purposes, chain wide benefits are defined as retail level revenue less chain wide costs (since we assume a fully integrated chain). As this measure of benefit does not, necessarily, cover the full set of costs, we refer to it as a gross margin. The latter can affect two factors beyond parental stock selection and management. Namely endpoint selection and revenue indexing based on quality.

Endpoint selection refers to the measurable point at which living animals are ready for processing (i.e. harvesting). The endpoint dimension used in this study will be progeny back fat, which will be treated as either an exogenous or endogenous effect (referred to as fixed endpoint and optimal endpoint, respectively) depending on the modeling strategy employed. In the model that follows, progeny back fat is set to a level of seven millimeters when a fixed endpoint selection method is used. Setting back fat at seven millimeters allows for comparison of all progeny with a consistent value for that trait. Optimal endpoint selection means one optimally chooses the point at which is to harvest an animal when chain wide gross margin for that progeny is maximized. The optimized endpoint method allows one to compare parental stock at a point where their progeny achieve their highest economic value.

Revenue quality indexing is the means by which differences in the composition of the end product affect the value of the progeny at time of retail sale. In determining the revenue quality indexing factor (a factor used to adjust individual progeny's revenue), several issues are identified. These include the degree to which compositional difference of the end product meet or affect consumers' valuation and whether the difference in the composition is consistent throughout all of the end product derived. Here, quality indexing of revenue will be viewed as a discounting from a base level. The next section brings these concepts together in an empirical model which contains a set of equations used to determine phenotypic traits of progeny from particular sire/dam pairings and a set of equations used to calculate the economic value of each progeny based on their phenotypic traits.

EMPIRICAL FRAMEWORK

The conceptual framework outlined an approach to determine the benefit of capturing supply chain information and applying it to upstream decision-making. Specifically, a decision maker within the vertically integrated beef supply chain is assumed to be faced with the following question: "which sire do we mate to a specific dam or dam group?" To operationalize the conceptual framework, an empirical model is needed. While presented for the specific case of beef cattle in a vertically integrated chain and with a fixed management strategy over a set sample of genetics, it could be extended to other circumstances.

The model consists of a series of equations used to model an integrated beef supply chain from the cow-calf level of production, through to the retail level. Phenotypic variables are calculated using formulae drawn from the animal science/breeding literature and across breed comparisons (ABC)[7] information provided by Beef Improvement Ontario (BIO)[8]. Cost and price information are utilized from an existing, but anonymous, integrated supply chain.

Figure 2 illustrates the flow of the model. With a fixed endpoint, the backfat level is set exogenously in the model, but is determined endogenously when the optimal endpoint method is used. Regardless, the level of backfat is combined with known genetic, production, and yield data to predict various phenotypic production levels and yields. Phenotypic levels for longissimus muscle area, backfat, and intramuscular fat traits are utilized in determining expected yield results for the processor and retailer units. Predicted production levels and yields are then used to calculate revenues and costs for the entire chain, in conjunction with the various quality index treatments, and ultimately, the economic value of the progeny. This approach to determining the monetary value of average progeny is new to the field in the sense that it provides a value which reflects consumers' value for the end product. Moreover, the bundling of economic and animal breeding methods, combined with the development of a new retail value chain calculator, offers a new contribution to both the agricultural economics and animal breeding literature.

Each progeny's gross margin is calculated as revenue minus chain wide costs:

$$\pi = R_{retail} - C \tag{1}$$

[7] ABC, also referred to as Across Breed Expected Progeny Differences, allows for a comparison of various traits across different breeds of animals.

[8] BIO provides genetic evaluation services to the Ontario beef industry

where π, R_{retail} and C are gross margin, retail revenue and chain wide costs, respectively, for the progeny under question. Retail level revenue is calculated as:

$$R_{retail} = (w_{rp} \times p_{rp}) \times (1 - adj_{rp}) \tag{2}$$

where w_{rp} is the retail-level weight from the respective progeny, p_{rp} is the retail price (which is exogenous) and adj_{rp} is a retail level quality index. Each progeny's retail weight is calculated as 60 percent[9] of their weight at endpoint attainment, times retail product and fat trim cutability prediction equations from Shackleford et al. (1995).[10] (These cutability equations depend on the level backfat, intramuscular fat and longissimus muscle area when then endpoint is attained and allow one to predict the amount of product derived from a carcass.)

The base (i.e. not discounted) retail price is calculated as a weighted average of the retail ready value of sub-primal cuts in Ontario. The weights in this calculation equal the sub-primal's percent share of total sub-primal weight. Retail ready sub-primal values were developed by modifying the sub-primal values reported in the Canadian Boxed Beef Report (George Morris Center 2004) to reflect retail yield from sub-primals. The resulting price $3.91 per pound.

Retail revenues are adjusted in the model for quality by price discounts based on intramuscular fat and longissimus muscle area. Five classes are used for intramuscular fat based on cut offs for Canadian marbling score classes. The classes are AAA+, AAA, AA, A, and B (greater than 8%, 8.00 to 5.04%, 5.04 to 3.83%, 3.83 to 2.76%, and less than 2.76% intramuscular fat, respectively). Longissimus muscle area is used as an indicator of size of cut. Longissimus muscle area classes are dispersed 22.6 cm^2 from each other from a base of 100 cm^2, the classes 1 to 5 being greater than 145.2, 145.2 to 122.6, 122.6 to 100, 100 to 77.4, and less than 77.4 cm^2,

[9] This value is the accepted average dressing percentage by the Ontario beef industry.

[10] Manipulations of the Shackleford et al. (1995) equations have occurred to correct for units.

respectively. Discounts were applied only to those sub-primals affected by intramuscular fat or longissimus muscle area, approximately 43% and 31% of total retail products, respectively.

Predicted mean phenotypic levels for intramuscular fat and longissimus muscle area are utilized along with variances of intramuscular fat and longissimus muscle area to calculate the distribution of expected progeny into five groups for both traits. The expected progeny groupings allow the model to deal with valuation of the various classes in the absence of a continuous pricing function for varying levels of the respective traits.

Four treatments of intramuscular fat and longissimus muscle area group valuation are used to portray different market place constraints on retail beef cuts meant to simulate the consumers' valuation, as affected by intramuscular fat and longissimus muscle area. Treatment 1 applies no discounts to retail product value of any kind, treatment 2 applies discounts to retail product for intramuscular fat effect, treatment 3 applies discounts to longissimus muscle area effect, and treatment 4 applies discounts to both intramuscular fat and longissimus muscle area effects. The combinations of discounts applied to treatments are shown in Table 1.

As mentioned, when the fixed endpoint method is utilized, the target level of backfat (tbf) is set as seven mm, which is a level adequate to finish in currently available sire ranking models. When the endpoint is optimized, backfat is a choice variable in a model which solves for backfat in order to maximize chain wide gross margins.[11] The age (of the progeny) required to meet the endpoint (doa_{tbf}) is calculated based on a predictive equation from Brethour (2000):

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[11] The gross margin is maximized by using the Solver function in Microsoft Excel version 10. The Solver target is a cell which contains the target backfat endpoint, which is non-negative, and has been set to maximize a cell that contains a function that aggregates the gross margins for the chain which is not constrained by any element.

$$doa_{tbf} = 365 + \frac{\ln(tbf) \quad \ln(avgbf + bf_{bull} + bf_{cow})}{0.01065 + (bf_{bull} + bf_{cow})/365} \tag{3}$$

where $avgbf$ is the average backfat at 365 days of age from the growing unit, and bf_{bull} and bf_{cow} are the sire and dam's ABC for backfat, respectively. Based on the age required to meet the endpoint, the remaining predicted phenotypic levels are calculated, (i.e., weight, intramuscular fat and longissimus muscle area of the progeny when the target (or optimal) backfat is attained).

To determine progeny weight when the target (or optimal) backfat is attained (w_{tbf}), the progeny's birth weight (w_0) is first calculated as $avgbw + bw_{bull} + bw_{cow}$, where $avgbw$ is the rearing unit's average birth weight and bw_{bull} and bw_{cow} are sire's and dam's birth weight ABCs, respectively. Weight at weaning (w_{200}) is calculated by adding the progeny's weaning gain to the birth weight. Weaning gain is calculated as $avgwg + wg_{bull} + wg_{cow} + 2milk_{cow}$, where $avgwg$ is the rearing unit average weaning gain, wg_{bull} and wg_{cow} are the sire and dam's weaning gain ABC, and $milk_{cow}$ is the dam's ABC for milk gain. The progeny's post weaning weight gain is next calculated as: $(avgpwadg + [pwg_{bull} + pwg_{cow}]/165) \times (doa_{tbf} - 200)$, where $avgpwadg$ is the average daily gain of animals in the feeding unit, and pwg_{bull} and pwg_{cow} are the sire and dam's post weaning gain ABCs, respectively. The sum of the dam and sire post weaning gain ABCs is divided by 165 days to get an average daily gain which is then added to the $avgpwadg$ and multiplied by the number of days in the feeding unit ($doa_{tbf} - 200$). The average progeny weight at endpoint attainment is calculated as:

$$\begin{aligned} w_{tbf} = {} & avgbw + bw_{bull} + bw_{cow} + avgwg + wg_{bull} + wg_{cow} + 2 \times milk_{cow} + \\ & (avgpwadg + [pwg_{bull} + pwg_{cow}]/165) \times (doa_{tbf} - 200) \end{aligned} . \tag{4}$$

The phenotypic level of intramuscular fat is determined by first calculating the progeny's predicted rate of daily intramuscular fat deposition, and them multiplying this amount by days of age when the target (or optimal) backfat level is attained:

$$imf_{tbf} = doa_{tbf} \times \frac{avgimf + imf_{bull} + imf_{cow}}{365} \tag{5}$$

where $avgimf$ is the average intramuscular fat at 365 days of age in the feeding unit, and imf_{bull} and imf_{cow} are the sire and dam's intramuscular fat ABCs, respectively. Longissimus muscle (i.e. ribeye) area is calculated in a similar manner:

$$rea_{tbf} = doa_{tbf} \times \frac{avgrea + rea_{bull} + rea_{cow}}{365} \tag{6}$$

where $avgrea$ is the average intramuscular fat at 365 days of age in the feeding unit, and rea_{bull} and rea_{cow} are the sire and dam's intramuscular fat ABC.

Chain costs include costs associated with the rearing, feeding, processing, and retailing units and are calculated on a per progeny basis. Equation (7) is used to calculate rearing costs:

$$\begin{aligned} C_{REAR} &= 0.025 \times avgweight_{cow} \times 365 \times P_{cowfeed} + 1.93 \times (bw_{cow} + bw_{bull}) + \\ &0.00248 \times (bw_{cow} + bw_{bull})^2 + wgcst \times (wg_{cow} + wg_{bull}) + 2 \times milk_{cow} \times mwgcst + avgweancst \end{aligned} \tag{7}$$

The first term ($0.025 \times avgweight_{cow} \times 365 \times P_{cowfeed}$) accounts of dam feed costs and is held fixed. Dam feed intake is calculated as 2.5 percent of the dam's mature weight per day, times the price of cow feed. The costs attributable to additional weight of calf pre-calving are calculated as $1.93 \times (bw_{cow} + bw_{bull}) + 0.00248 \times (bw_{cow} + bw_{bull})^2$ and represents the cost of an additional pound of birth weight ($bw_{cow} + bw_{bull}$) when $bw_{cow} + bw_{bull}$ is greater than zero. Additional costs associated with heavier progeny at the time of weaning ($wgcst \times (wg_{cow} + wg_{bull})$), are calculated as the price of an additional unit of weaning gain (*wgcst*) times the additional weaning gain

($wg_{cow} + wg_{bull}$). Additional weight of progeny at weaning time attributable to dam milk ($2 \times milk_{cow}$) is considered and the cost associated with the extra weight ($mwgcst$) is multiplied by the $2 \times milk_{cow}$. Various fixed costs associated with keeping a cowherd for 365 days, represented as *avgwncst*, are also added.

Feeding unit costs (C_{feed}) reflect the cost of feeding and keeping a steer from 200 days of age to the age at which the target (or optimal) backfat is attained, and is calculated as: $C_{feed} = d_{feed} \times (FI \times p_{steerfeed} + yardcst + financecst) + c_{health}$ where d_{feed} is days on feed, FI is per day feed intake, $p_{steerfeed}$ is the price of steer feed, $yardcst$ is yard cost per day of feed, $financecst$ is the finance cost per day on feed and c_{health} is a fixed cost for health. Days on feed equals age (in days) at endpoint attainment less 200 days (for weaning, etc). Steer feed intake, FI, is calculated following Guiroy (2001).

Processing costs ($C_{process}$) are made up of average overhead operating costs per pound of carcass processed ($w_{carcass} \times avgprocst$). Processor and retail rendering costs are calculated as $(w_{tbf} - w_{rp}) \times p_{rend}$, where p_{rend} is the per pound cost of rendering, and $w_{tbf} - w_{rp}$ is the weight of rendered product. Retailing overhead costs ($w_{rp} \times avgretailcst$) are the product of the retail product weight times the average retail unit overhead cost per pound of retail product. Cost associated with the act of aging retail product for 21 days is incorporated as the shrink in retail product value ($retailshrink\% \times R_{retail}$) and 21 days worth of interest cost ($dailyin \times 21$) on the retail inventory.

DATA

This study uses genetic data created from bull evaluations carried out on a group of calves born at the Elora Beef Research Centre and New Liskeard Agricultural Research Centre. Bull calves (n =

48) sired by Angus (n = 22), Hereford (n = 4), Simmental (n = 9), Gelbvieh (n = 8) or crossbred (n = 5) bulls bred to crossbred dams (average breed composition 40 percent British breeds, 57 percent Continental breeds, 3 percent dairy breeds) were born in the spring of 2002. These calves were part of an ongoing beef-cattle genetics research program conducted by the University of Guelph. Calves were raised at the University of Guelph's Elora Beef Research Center from weaning until slaughter in the spring of 2003.

The ABCs for the sire's birth weight (BW), weaning gain (WG), post-weaning gain (PWG), intramuscular fat (IMF), longissimus muscle area (REA), and back fat (BF) are shown in Table 2. Since the dam's bred to these bulls are assumed to have a median level for all traits, Table 2 also shows the median level of the dam ABCs for these traits, as well as that for milk (MILK). The median levels of all traits are utilized as they most closely represent a conceivable mix of traits. The median level is determined by the 50th percentile traits of calves born in the last five years (1997 to 2002); these data were provided by BIO and are available upon request. Other exogenous variables/data are listed in their order of appearance in Table 3.

RESULTS

Table 4 shows summary statistics of the progeny traits (i.e. phenotypic characteristics) resulting from a pairing of each bull and a cow with a median level of traits. When the fixed endpoint method is used, target backfat is pre-determined, so the traits in Table 4 do not vary with the treatment (i.e. price discounting). However, traits do vary across treatment when the optimal endpoint selection criterion is used.

Phenotypic Variation across Endpoint Methods and Treatments

When the fixed endpoint criterion is used, progeny from the 50 pairings are younger and lighter then when the optimal endpoint criterion is used. Moreover, because of this, these progeny tend to have smaller longissimus muscle areas and less intra-muscular fat compared to outcomes when an optimal endpoint is used. These phenotypic differences reflect the fact that the animal spends fewer days on feed with a fixed endpoint

When the optimal endpoint criterion is used, phenotype traits vary across treatments. This is because the endpoint occurs when the margin is maximized, which depends on the nature of the discounting (i.e. treatment effect). When carcasses are discounted on the basis of intramuscular fat only (i.e. Treatment 2), progeny are fed for a longer period time and consequently weigh more and have greater longissimus muscle area then when no discounting is applied with the optimal endpoint method. When discounts are applied to larger longissimus muscle areas (i.e. Treatment 3), progeny are fed for shorter periods of time, weight less and have smaller longissimus muscle area then when no discounting is applied. Age, weight and other phenotypic characteristics in treatment 4, where IMF and REA are the basis for discounting, fall between those for treatments 2 and 3, but are above those for treatment 1. With the optimal endpoint method, variation in phenotypic levels is directly due to the level of backfat that each progeny is allowed to attain and not changes in genetics. The varying levels of backfat lead to varying levels of age and therefore time on feed, and consequently, varying levels of longissimus muscle area and intramuscular fat.

Financial Performance of Progeny across Endpoint Methods and Treatments

For comparative purposes, Figures 2 and 3 plot the gross margin for each sire in each treatment, according to whether the fixed or optimal endpoint method is used. When a fixed endpoint is used (see figure 2), treatment 1 has the highest gross margin, followed by treatments 3, 2 and 4. Margins within treatment 1 are largest as there is no discounting based on intramuscular fat or longissimus muscle area level. Revenues in treatment 3 are indexed (discounted) for longissimus muscle area quality effects – an effect which does not appear to generate appreciably different results compared to treatment 1. In treatment 2, progeny revenues are indexed for intramuscular fat quality effects. As will be noted later, the lower gross margins in treatment 2 (and 4) are mainly due to the direct indexing of revenue, with the remaining decline in gross margin relate to a cost affect. In treatment 4, progeny revenues are indexed for both intramuscular fat and longissimus muscle area quality effects. The inclusion of the intramuscular fat indexing factor in this treatment greatly affects the level of expected progeny gross margin.

Table 5 shows summary statistics of the financial measures generated in the model, namely the mean and standard deviation of the retail revenue index factor (which reflect discounting in the respective treatments) revenue, cost and gross margin across endpoint selection methods and treatments. What is particularly interesting is that differences in average gross margin across treatments are driven largely by differences in revenue not costs. Specifically, retail revenues are heavily discounted when intramuscular fat is the basis of carcass quality assessment. For instance, average retail revenue indices are lower in treatments 2 and 4 (which involve IMF discounting) than in treatments 1 and 3 (which have no discounting and REA discounting, respectively). Consequently, average retail revenues are around $300 less when discounting includes intramuscular fat, but average costs in the same treatments are only $10 less. Treatments with IMF discounting have systematically lower revenues and gross margins. Lastly, within the fixed endpoint criterion method, differences in average progeny returns across treatments were statistically different from zero at the one percent level (all p-values$<10^{-3}$).

Figure 3 plots the return to each progeny arising when the optimal endpoint method is used. Again, treatment 1 (which has no discounting) has the highest chain-wide gross margin, followed by treatments 3, 2, and 4. As with the fixed point method, treatments where IMF discounting is present (i.e. treatments 2 and 4) result in systematic lower returns. Table 5 shows the summary statistics for the financial measures with the optimal endpoint scenario. These results further echo the main conclusions from Figure 2 and from the discussion with the fixed endpoint – treatments with IMF discounting have lower returns. While the root cause of these differences is a reduction in revenue (due to IMF discounting), costs in treatments 2 and 4 are actually higher than costs in treatment 1 and 3. As with the fixed endpoint method, the inter-treatment differences in progeny gross margins in the optimal endpoint scenario are statistically different from zero at the one percent level.

Nevertheless, for each treatment, the optimized endpoint approach returns higher gross margins than the fixed endpoint. The driver of the higher optimal endpoint margins is a larger increase in revenue than costs. Moreover, given these results, one might conclude that the industry practice of using seven mm of backfat as a fixed endpoint is suboptimal, as gross margins can be increased by increasing the endpoint level to be in line with the optimal endpoint level. With one exception, differences in treatment specific gross margins across fixed and optimal endpoint selection methods are significantly different from zero at the five percent level. The difference in fixed and optimal endpoint gross margins is not statistically different from zero (*p*-value=0.338) in treatment 3. With this one exception, gross margins are statistically higher with the optimal endpoint method, further echoing the conclusion that use of a fixed endpoint may result in economically sub-optimal production and managerial decisions.

Ranking of Bulls based on Endpoint and Treatment

One question that might come to mind is whether the ranking of the bulls is the same regardless of the endpoint method and treatment. To examine this, recognize that in this study, each progeny's gross margin is used to rank the sire. The higher the progeny's gross margin, the higher the bull's rank (a bull whose progeny are more valuable will be valued more than a bull whose progeny have a lower value). Rather than compare the rankings directly, the correlation between gross margins within and across endpoint methods and treatments have been calculated and are shown in Table 6.

All correlation coefficients in Table 6 are significant (p-value=0.000). Within the fixed endpoint method, cross-correlations between gross margins range from 0.58 to 0.98. Cross-correlations within the optimal endpoint method range from 0.65 to 0.96, and are generally higher than those from the fixed endpoint method. Regardless of which endpoint method is used, cross-correlations are lower for treatment combinations involving intramuscular fat discounting (i.e. treatments 2 and 4) with treatments that do not discount on IMF (i.e. treatments 1 and 3).

Across all treatments, the correlation between margins from the fixed and optimal endpoint method are all larger than 0.96 (and are highlighted as the bolded diagonal elements on the bottom left hand quadrant of Table 6). Note that margins in treatments 2 and 4 had the lowest within treatment correlation (0.966 and 0.979, respectively). These treatments include discounts to cuts with lower intramuscular fat (treatment 2 discounts only on the basis of IMF, while 4 discounts on the basis of IMF and REA). Nevertheless, the strong association between the fixed and optimum endpoints indicates that within a particular discounting environment, there might be little value in determining optimal progeny endpoints. Recognize, of course, that the level of gross margin (or return) matters significantly when considering different endpoint methods – margins might be correlated, but choosing an optimal endpoint should lead to higher economic benefits. Moreover, it is important to reiterate the importance of the environment within which we are applying these results. The genetic population we evaluate might not display the same degree of genetic diversity that might be found elsewhere in the beef population.

Correlations between treatments and endpoint methods are reported for completeness, but are not terrible informative. Nevertheless, these correlations reflect the numerical value of correlations of margins within a particular endpoint method. Moreover, they also reflect the same role IMF discounting played above. Margins from treatments with IMF discounting have lower correlation coefficients with respect to margins with REA or no discounting.

Comparing Ranking Sire Methods

From a managerial point of view, it is important to note that using gross margins to rank sires is but one possible ranking method. Other ranking methods have been developed in the animal science/breeding literature. The question then becomes how do sire rankings based on progeny value compare to sire rankings based on other methods. Table 7 shows the Spearman rank correlation coefficients between the sire rankings based on progeny value and other sire ranking methods.

Naturally, the other sire ranks are calculated using sire, dam and progeny information used in the simulation model developed here. The other sire ranking methods are: the Dickerson Selection Index[12] (DSI) (Dickerson et. al, 1974), Prime Plus (PP) a selection index targeting high intramuscular fat products used by BIO, Beef Builder (BB) a selection index targeting yield of retail beef products used by BIO, and simple trait rankings of birth weight (BW), weaning gain (WG), intramuscular fat (IMF), longissimus muscle (i.e. ribeye) area (REA), backfat thickness (BF), and post weaning gain (PWG). In all of the rankings described, the larger the selection index value or trait ABC, the better, except in the case of BW and BF where it is more desirable to have lower trait ABCs (i.e. the lowest BF or BW trait ABC will be ranked number one, the second lowest BF or BW trait ABC will be ranked number two).

Rank correlations between the gross margin based sire rankings and other sire ranking methods appear sensitive to whether an optimal or fixed endpoint method is used. While differences exist within a particular treatment (e.g. compare rank correlations for treatment one,

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[12] The Dickerson Selection Index Values are calculated at the age constant ABC values of the 48 sires to be utilized in producing progeny for use within the proposed chain as,

$$DSI_{value} = \left(bw_{bull} + wg_{bull} + pwg_{bull}\right)/2.2046 \quad 3.2 \times bw_{bull}/2.2046 \quad 2.9 \times bf_{bull}$$

across endpoint methods), these differences do not appear significant. In terms of broad concordance of the alternative ranking methods with the gross margin ranking method, the gross margin ranks are positively and strongly correlated with the DSI rankings, followed by a positive but not as strong correlation with backfat (BF), weaning gain (WG), post-weaning gain (PWG), longissimus muscle area (REA) and Beef Builder (BB). The gross margin ranks are negatively correlated with ranks from Prime Plus (PP), intramuscular fat (IMF) and birth weight (BW). For a number of the alternative selection indices, the rank correlations with the gross margin ranks are not statistically different from zero (e.g. Prime Plus, Beef Builder, IMF and REA).

A number of points are worth noting. Birth weights generally tend to be correlated with other weight traits such as gain. The negative association between BW and gross margin based ranks might indicate the importance of other possibly correlated traits (i.e. weaning gain and post-weaning gain). Birth weight is a trait which the breeding decision maker (rearing unit) in the non-integrated supply chain place a high degree of emphasis to ensure a low incidence of dystocia. The weak negative association might indicate that without chain-wide information internalization, sub-optimal breeding decisions might be made.

The gross margin ranks weak to moderate associations with all other methods of selecting beef sires that are readily available. The current model includes processing and retailing unit costs and retail revenues which is different than the other readily available methods and which might be responsible for the lack of a strongly associated alternative method. This might indicate that the decision maker within the vertically integrated supply chain might be wise to choose a method for selecting sires other than that which is readily available, as the significance that a change in rankings has on gross margins has previously been explored.

SUMMARY AND CONCLUSIONS

A model that predicts the benefit from using beef progeny of a specified sire and dam mating, within a vertically integrated beef supply chain utilizing genetic evaluation, is developed. Progeny benefits are calculated based on their use within the vertically integrated supply chain as quality indexed retail cuts. Progeny benefit is reported as chain-wide gross margin assuming that one progeny is borne to a dam per annum. Progeny gross margins are then used to rank sires of the progeny. Rankings are used as a tool to make hypothetical breeding decisions within the vertically integrated supply chain.

Fixed and optimal endpoint (the point at which progeny are harvested for processing into retail cuts) methods are examined. Four treatments of quality indexing are applied in conjunction with the two different endpoint selection methods. Treatments assumed no discounting, discounting based on longissimus muscle area alone, intramuscular fat area alone and lastly, longissimus muscle area and intramuscular fat content together. The four treatments generated statistically significant differences in mean gross margins within the group of sires evaluated. Within each treatment, the optimal endpoint selection method generated statistically different and larger gross margins than the fixed endpoint method, except for the longissimus muscle area discounting treatment, where the difference was not significant. Across endpoint selection methods, the highest progeny gross margins resulted from no quality indexing, followed by discounting based on longissimus muscle area, then intramuscular fat content (i.e. marbling) and lastly discounting based on longissimus muscle area and intramuscular fat content. Quality indexing based on intramuscular fat content lowers gross margins as the ideal level of intramuscular fat is quite high in relation to the evaluated group of sires and dams ability to produce high intramuscular fat level progeny.

Lower gross margins are realized with the fixed endpoint method (i.e. when target backfat is set at seven mm) than with the optimal endpoint. This suggests that the marginal value product with a fixed endpoint is higher than the marginal factor cost and that use of the fixed endpoint (in this case backfat) method, within the context of a vertically integrated supply-chain, is sub-optimal and results in lower economic benefits.

The association of sire rankings across endpoint selection methods was consistently strong and indicates that within the group of 48 sires, few changes in ranking occurred due to the change in endpoint selection methods. The association of rankings between the treatments within endpoint selection methods was moderate to strong indicating that some changes in ranking occurred due to the change in the quality indexing factors. However, the association between a gross margin based ranking of sires and other ranking models was varied, and reflected a need to use an economic basis for sire selection (i.e. gross margin) as opposed to a production based or trait drive basis for sire selection.

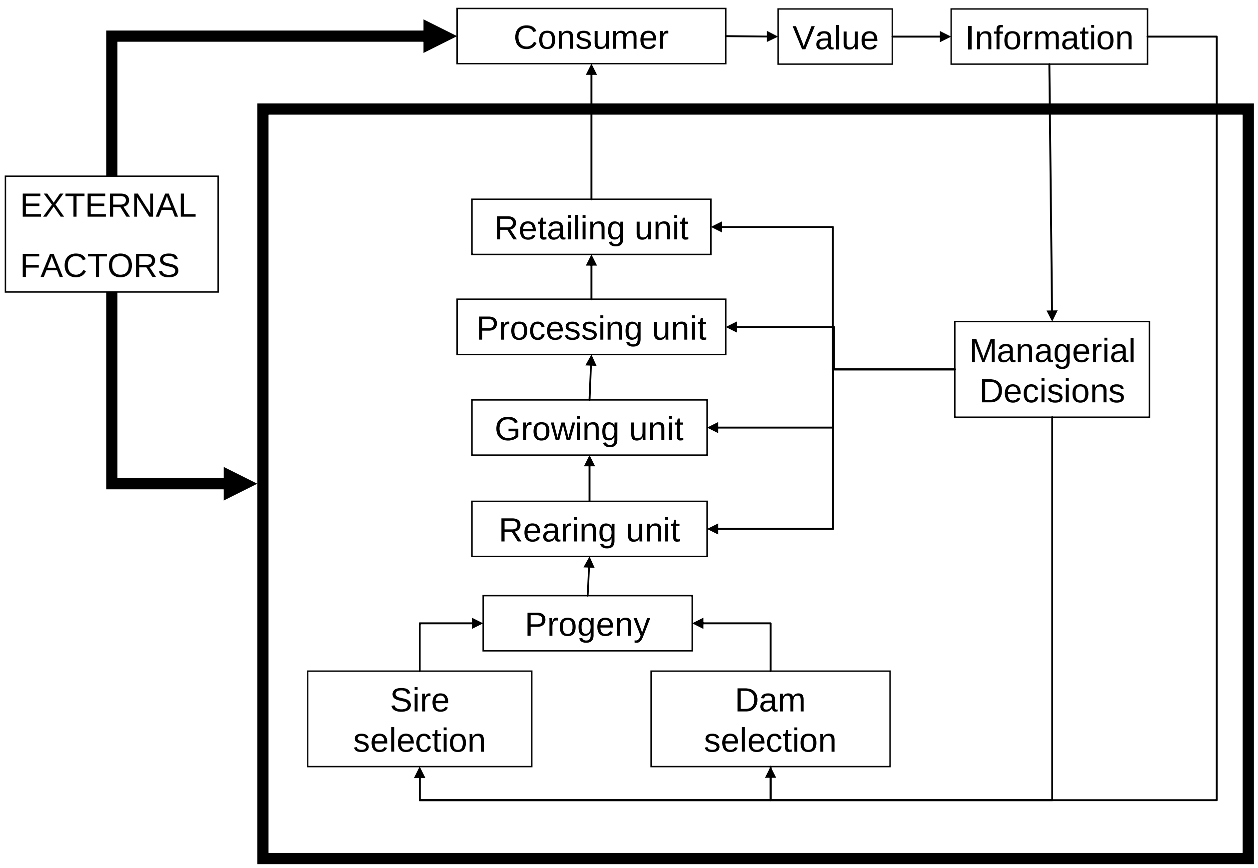


Figure 1: Schematic of the integrated supply chain

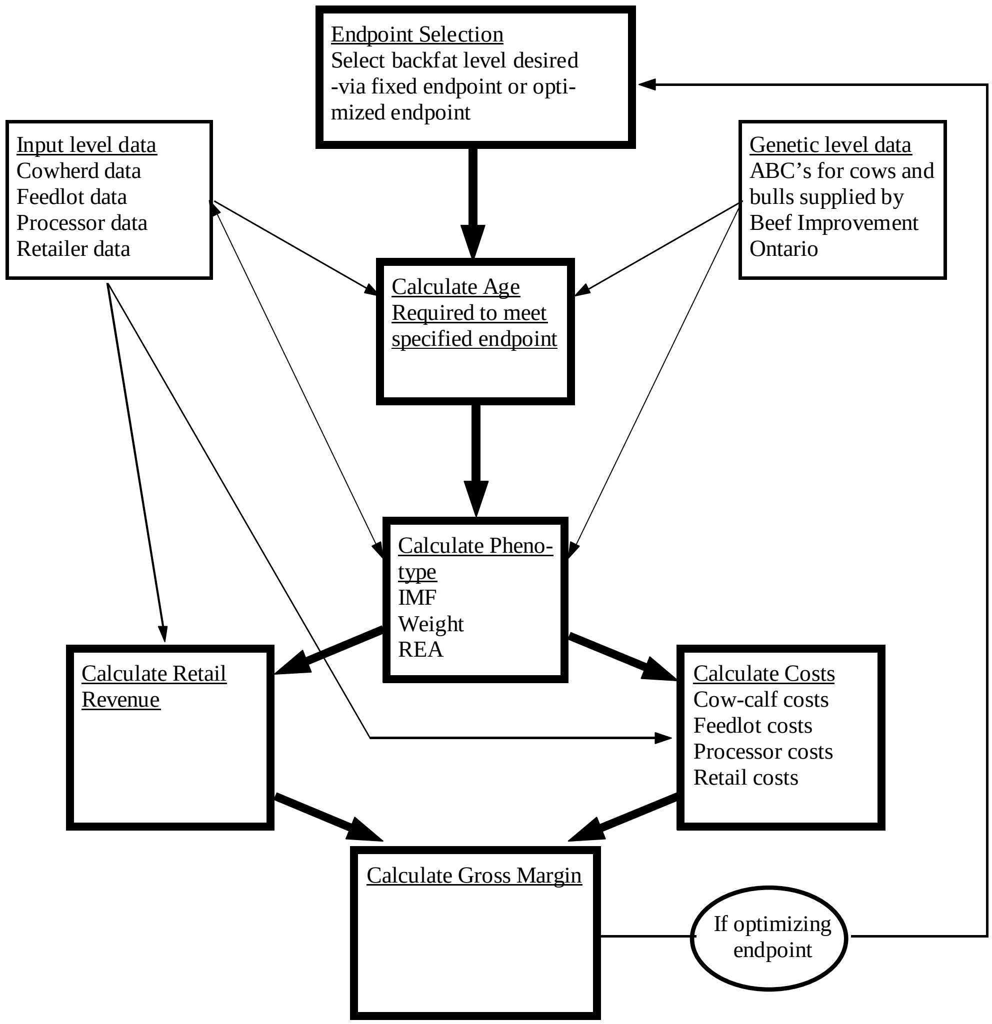


Figure 2: Flow Chart of Model

Table 1: Discounts of Intramuscular Fat and longissimus muscle Area Classes in Four Treatments of Quality Indexing of Retail Product

Treatment	Intramuscular fat class					Longissimus muscle area class				
	AAA+	AAA	AA	A	B	Class 1	Class 2	Class 3	Class 4	Class 4 -
1	0	0	0	0	0	0	0	0	0	0
2	0	0.1	0.2	0.3	0.8	0	0	0	0	0
3	0	0	0	0	0	0.7	0.35	0.1	0	0
4	0	0.1	0.2	0.3	0.8	0.7	0.35	0.1	0	0

Source: Authors' calculations

Table 2: Summary Statistics for Sire and Data ABCs

	BW	WG	PWG	BF	REA	IMF	MILK
				SIRE			
Mean	-2.21	38.69	32.93	0.20	-0.06	0.14	
Standard Deviation	3.45	9.25	12.37	0.29	0.23	0.15	
Max	4.88	59.99	55.40	1.06	0.41	0.63	
Min	-9.40	11.22	1.72	-0.38	-0.76	-0.15	
				DAM			
Median Level	0.30	31.40	22.80	-0.27	0.12	-0.06	15.90

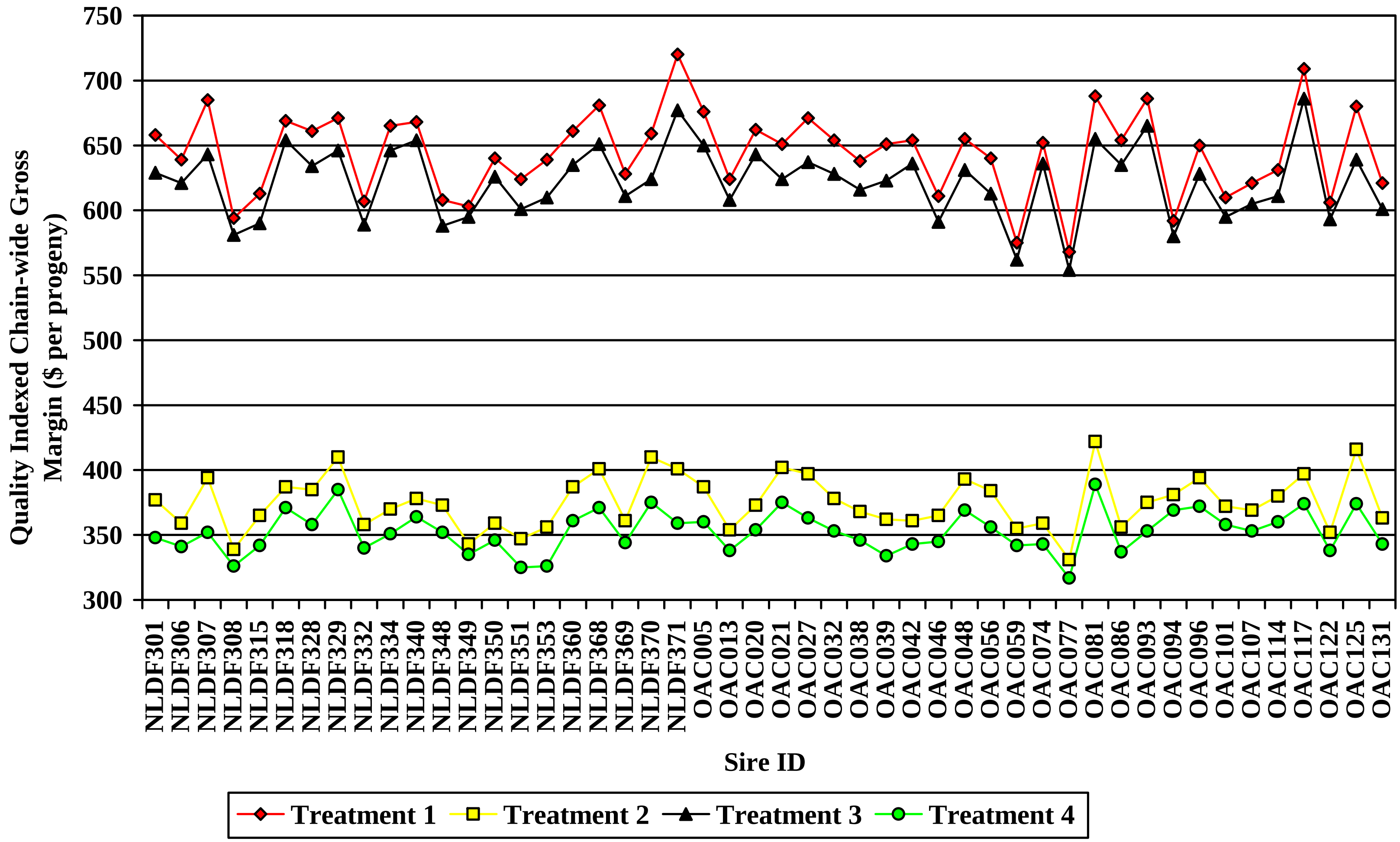
Table 3: Descriptions of Exogenous Variables/Data

Variable	Description	Value	Units
p_{RP}	Retail price	$3.91	$ per pound of retail product
avgbf	Backfat	5.00	millimetres at 365 days
avgbw	Birth weight	85.7	Pounds
avgwg	Weaning gain	461.0	Pounds
avgpwadg	Post-weaning average daily gain	3.37	pounds per day
avgimf	Intramuscular fat	3.10	percentage at 365 days
avgrea	Longissimus muscle area	14.50	square inches at 365 days
avgweightcow	Cow Mature Weight	1,400.0	Pounds
wgcst	Weaning gain cost	0.14	$ per pound of weaning gain
$p_{cowfeed}$	Cow feed price	0.03	$ per pound
mwgcst	Maternal weaning gain cost	0.32	$ per pound of weaning gain
avgwncst	Weaning gain cost	200.00	$ per progeny
$p_{steerfeed}$	Progeny feed price	0.08	$ per pound
yardagecst	Yardage cost	0.25	$ per progeny per day on feed
financecst	Interest cost	0.22	$ per progeny per day on feed
c_{health}	Health cost	20.00	$ per progeny
avprocst	Processor unit cost	0.05	$ per pound of carcass
avretailcst	Retailer unit cost	0.38	$ per pound of retail product
p_{rend}	Rendering unit cost	0.027	$ per pound of rendering material
retailshink%	Retail shrinkage	3.50	Percent of retail product
dailyin	Daily carrying cost	2.2%	Applied to the value of retail inventory holdings

Source: Authors' calculation

Table 4: Summary Statistics of Progeny Traits using Fixed and Optimal Endpoint Selection Criteria

		Optimal endpoint method			
Item	Fixed endpoint method	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Days of age at attainment of endpoint	386.1	419.4	434.4	395.5	415
	5.83	11.27	12.11	9.54	11.24
Weight at attainment of endpoint (lbs)	1190.4	1304.6	1356.2	1222.5	1289.5
	29.81	46.7	49.91	40.42	46.76
Longissimus muscle area at attainment of endpoint (in^2)	15.2	16.5	17.1	15.5	16.3
	0.37	0.58	0.62	0.5	0.58
Intramuscular fat at attainment of endpoint (%)	3.5	3.8	3.9	3.6	3.7
	0.14	0.14	0.14	0.14	0.14
Backfat at attainment of endpoint (mm)	7	10.4	12.4	7.8	9.9
	0	0.41	0.49	0.32	0.47
Feed intake at attainment of endpoint (pounds DM per head per day)	19.1	20.1	20.7	19.3	20
	0.47	0.52	0.53	0.5	0.52
Carcass weight (lbs)	714.2	782.8	813.7	733.5	773.7
	17.89	28.02	29.95	24.25	28.06
Rendered product weight (lbs)	695.7	776.8	816.6	717.7	765.6
	15.71	27.04	29.41	22.79	27.15



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2 **Figure 3: Progeny Gross Margins over Four Treatments of Quality Indexing Factors using the Fixed Endpoint Criteria**

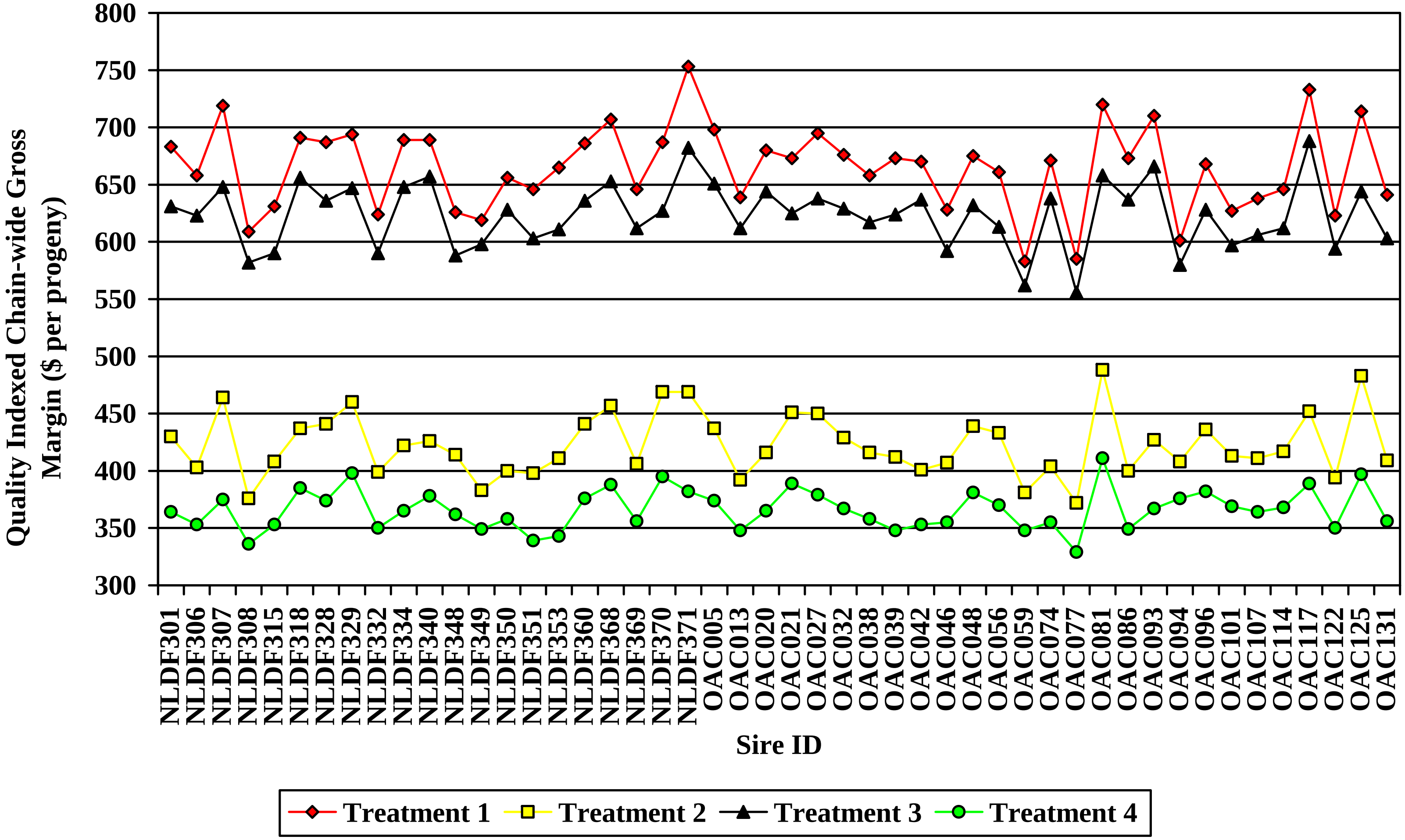

Figure 4: Progeny Gross Margins over Four Treatments of Quality Indexing Factors using the Optimal Endpoint Criteria

Table 5: Summary Statistics of the Financial Characteristics of Progeny using Fixed and Optimal Endpoint Selection Criteria

	Fixed Endpoint				Optimal Endpoint			
	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Retail Revenue Index	1	0.86	0.99	0.84	1	0.88	0.98	0.85
	0	0.01	0.004	0.011	0	0.008	0.005	0.01
Revenue	1932.25	1653.33	1909.08	1630.16	2061.96	1862.4	1940.44	1737.41
	56.09	41.55	50.76	35.85	77.34	69.61	60.58	54.28
Cost	1287.98	1278.22	1287.17	1277.41	1396.82	1439.64	1316.93	1371.28
	23.78	23.23	23.58	23.03	41.18	44.29	34.43	40.19
Gross margin	644.27	375.11	621.91	352.75	665.14	422.76	623.51	366.14
	33.05	20.78	28.3	16.08	37.48	27.6	28.76	17.85

Table 6: Correlation coefficients between margins

	FT1[a]	FT2[b]	FT3[c]	FT4[d]	OT1[e]	OT2[f]	OT3[g]	OT4[h]
FT1	1.000							
FT2	0.724	1.000						
FT3	0.978	0.647	1.000					
FT4	0.598	0.936	0.582	1.000				
OT1	**0.996**	0.734	0.959	0.586	1.000			
OT2	0.812	**0.966**	0.716	0.836	0.836	1.000		
OT3	0.980	0.646	**0.999**	0.576	0.963	0.721	1.000	
OT4	0.692	0.974	0.653	**0.979**	0.694	0.921	0.652	1.000

[a] FT1 denotes fixed endpoint method and treatment 1
[b] FT2 denotes fixed endpoint method and treatment 2
[c] FT3 denotes fixed endpoint method and treatment 3
[d] FT4 denotes fixed endpoint method and treatment 4
[e] OT1 denotes optimal endpoint method and treatment 1
[f] OT2 denotes optimal endpoint method and treatment 2
[g] OT3 denotes optimal endpoint method and treatment 3
[h] OT4 denotes optimal endpoint method and treatment 4

Table 7: Rank Correlation Coefficients between Gross Margin Based Ranks and Other Sire Ranking Methods[a]

	DSI[b]	PP[c]	BB[d]	BW[e]	WG[f]	PWG[g]	IMF[h]	REA[i]	BF[j]
FT1	0.908	-0.324	0.330	-0.470	0.580	0.606	-0.654	0.346	0.629
	(0.000)	(0.025)	(0.022)	(0.001)	(0.000)	(0.000)	(0.000)	(0.016)	(0.000)
FT2	0.724	-0.047	0.352	-0.393	0.483	0.399	-0.031	0.504	0.583
	(0.000)	(0.749)	(0.014)	(0.006)	(0.001)	(0.005)	(0.835)	(0.000)	(0.000)
FT3	0.854	-0.338	0.281	-0.533	0.636	0.700	-0.690	0.183	0.498
	(0.000)	(0.019)	(0.053)	(0.000)	(0.000)	(0.000)	(0.000)	(0.213)	(0.000)
FT4	0.624	0.009	0.267	-0.477	0.513	0.490	0.110	0.285	0.397
	(0.000)	(0.954)	(0.067)	(0.001)	(0.000)	(0.000)	(0.455)	(0.050)	(0.005)
OT1	0.918	-0.354	0.304	-0.453	0.537	0.554	-0.656	0.361	0.687
	(0.000)	(0.014)	(0.036)	(0.001)	(0.000)	(0.000)	(0.000)	(0.012)	(0.000)
OT2	0.830	-0.164	0.320	-0.353	0.452	0.368	-0.215	0.510	0.729
	(0.000)	(0.265)	(0.026)	(0.014)	(0.001)	(0.010)	(0.142)	(0.000)	(0.000)
OT3	0.855	-0.354	0.271	-0.529	0.626	0.691	-0.701	0.181	0.506
	(0.000)	(0.014)	(0.063)	(0.000)	(0.000)	(0.000)	(0.000)	(0.219)	(0.000)
OT4	0.711	-0.079	0.268	-0.449	0.502	0.489	-0.004	0.303	0.510
	(0.000)	(0.594)	(0.066)	(0.001)	(0.000)	(0.000)	(0.977)	(0.037)	(0.000)

[a] Values in parentheses are 2-tailed *p*-value
[b] DSI denotes the Dickerson Selection Index rank
[c] PP denotes the Prime Plus Selection Index rank
[d] BB denotes the Beef Builder Selection Index rank
[e] BW denotes birth weight trait rank
[f] WG denotes weaning gain trait rank
[g] PWG denotes post-weaning gain trait rank
[h] IMF denotes intramuscular fat trait rank
[i] REA denotes longissimus muscle area trait rank
[j] BF denotes backfat trait rank

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